Investigation of High-Tension Switching Equipments

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INVESTIGATION OF HIGH-TENSION SWITCHING EQUIPMENTS

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INTRODUCTION.

Probably no branch of Electrical Engineering has developed so rapidly in the last ten years as has the generation and distribution of high voltage alternating current. This has been so rapid that the existing literature and data on the subject are widely scattered. This is particularly true of the switching equipment which, while it is in one sense of the word an incidental, is still of great importance to the successful operation of a generating station.

It is a well known fact that the conditions affecting the various problems connected with high voltage switching are widely different and an effort to state definite rules will be useless. Therefore we shall not be able to suggest any particular equipment for a plant as no standard has been reached in this part of the design; still it is hoped that, by pointing out some of the advantages and disadvantages of some of the typical equipments which we have found in operation, we may be able to show the proper equipment to be used where certain conditions are found.

In this paper it is assumed that the generators are chosen and located, that the distributing system is determined, and that the transformers are chosen. In short we shall assume that there is a gap between the generators and the feeders which must be filled in by certain leads, bus bars, switches, instruments, protective devices, and other apparatus. It is our object to investigate what is used to fill in this gap and to point out as far as possible the best way to do it.

METHODS OF CONNECTING POWER CIRCUITS.

Without Transformers.

The simplest case to consider is where one generator is supplying energy to one feeder thru a switch, as shown in Fig.1, Plate 1. As the number of feeders for one generator increase a bus bar is put in and the generator and each of the feeders is connected to it thru a switch. This is shown in Fig.2, Plate 1.

Where the capacity of the plant requires two generators and they are to be run in parallel, each of the generators and feeders is connected to a bus bar as indicated in Fig.3, Plate 1. In addition we have a sectionalizing switch so that each generator and its feeder can be operated as a single unit. The advantage of this method is that it is possible to connect a feeder which is giving trouble to a separate generator and thus allow better regulation of the rest of the system.

Fig.4, Plate 1, shows a system where the total energy generated can be measured on one meter. But it does not have the advantage mentioned for the scheme in Fig.3, Plate 1. It is often desirable to have a duplicate set of bus bars so that one set can be cut out and cleaned while the other carries the load. This would be necessary where the bus bar is exposed to dust, which if not removed would aid static discharges and lead to further trouble. This scheme is shown in Fig.5, Plate 1, where it can be seen that each generator and feeder is supplied with a selector switch by means of which it can be

connected to either bus bar. Sectionalizing switches are also provided for the reasons mentioned in the case shown in Fig.3,Plate 1. Fig.4,Plate 1, shows the same scheme with a slightly different arrangement of switches. A main switch is placed in the generator lead and then disconnecting switches are placed in the branch leads going to each bus bar. With this arrangement the operator has two different kinds of switches to manipulate to make a change. However the cost of installation is lower.

Fig.6,Plate 1, shows a scheme which is used at the St. Anthony Falls Power Co. There are three 750 K.W. generators connected as shown. Here each unit can be run independently with its own feeder or all units can be connected in parallel by means of either of the duplicate bus bars. Both busses can be connected in parallel or any generator or feeder can be disconnected. This is,of course,a special case where there are as many feeders as generators. This scheme is practically the same as that shown in Fig.5,Plate 1,but is better. In Fig.5 we have a sectionalizing switch and in Fig. 7,Plate 1,we have not. However in Fig.7 it is seen that there are the same number of switches between a generator and its feeder as there are in Fig.5 and still we can accomplish exactly the same results. Hence the scheme shown in Fig.5 requires two switches more than are necessary.

The scheme shown in Fig.8,Plate 1, is the one which is used by the Ontario Power Co. at Niagara Falls on the 12,000

volt feeders. It can be seen that there is a similarity between this scheme and the one used by the St. Anthony Power Co. The only difference is in the addition of a switch between a generator and its feeder which makes the latter system more flexible. Since transformers are fed from the same bus bar it will be necessary to leave this case until we take up plants with transformers.

In central stations where there are a large number of generators and feeders, as for instance the New York Rapid Transit Central Station, where there are 12 generators and 64 feeders, we note the use of a feeder group switch. The scheme is shown in Fig.9, Plate 1. There is a duplicate set of bus bars and each generator has selector switches. Then we have a number of feeder group busses each of which is connected to the main busses by means of group selector switches. The feeders connect to the group bus thru switches. In this system of feeders a sub-station is fed from different groups so that in case a cable of one group is thrown out the service is continued thru other feeders from other groups. Under normal conditions all feeders operate in parallel to cut down the line loss as much as possible.

In Fig.10, Plate 1, we note the scheme of the Brooklyn Edison Co. where three sets of bus bars are used which can be operated independently or in parallel by using the tie switches. Each generator has three selector switches and the feeders are connected to the main busses thru anyone of their three selector switches.

Fig.11, Plate 1, shows the connections used at the Brussels Power Station. Only one set of bus bars is used here and the three sub-stations are fed from each of the different sections of the bus. This is arranged for continuity of service and has the same advantage in regard to feeding the sub-station as was mentioned under the scheme shown in Fig.9.

With Transformers.

The method of connecting the transformers in three-phase systems has not been made standard as yet and we find some who advocate the delta connection and some who favor the star connection. In general it may be said that it has been found customary to connect the high voltage side of a transformer star and ground the neutral, thus lowering the strain on the insulation in the system. In the star system the higher harmonic E.M.F's. cannot circulate current in the winding although it will increase the frequency in the grounding wire. On the other hand, if the delta connection is made, the higher harmonics will cause a current of higher frequency than that of the supplier to flow in the delta this increasing the core loss. Where the high voltage side of the transformers is connected star, the low voltage side is usually connected delta. As to the proper method in this case we cannot say but the general tendency has been as mentioned. We find this system used by the latest central stations, which is an indication of its reliability. Further than this we will not discuss the connections of transformers since the practice is standard in other systems.

In the connecting of the transformers into the main power circuit we find, from studying the various schemes, that in general the secondary side of the transformer is treated as a generator for the feeders and the primary as the feeder from the generators. A glance at the diagrams in Plate 2 will show this.

In the simplest case, we have a generator feeding into the primary of a transformer which sends energy into the feeder thru a switch. The generator and transformer in this case comprise a simple high voltage unit and cost of operation is low. This scheme is shown in Fig. 12. As the number of feeders is increased there is added a bus bar to the secondary side of the transformer thru a switch. This scheme has been adopted by the Aurora, Elgin, and Chicago Ry. Co. in their power plant at Batavia, Illinois, and is giving perfect satisfaction and, as mentioned above, has the advantage of low cost of operation. Fig. 13 shows this. In Fig. 14 we have a similar scheme where a switch is placed between the transformer and the generator, thus increasing the cost of operation, but in case the switch is automatic it protects the generator against trouble which might arise in the transformer.

An increase in the number of generators requires a scheme similar to that shown in Fig. 15. There is one low-tension bus bar and one high-tension bus bar each of which can be sectionalized thus making two independent stations. Fig. 16 shows the condition where the generators have selector switches

by means of which they can be connected to the bus bars or primary of the transformers. The primary bus bar need not be sectionalized for the operation of the generators and transformers as independent units. This can be accomplished by leaving the selector switch for the bus bar open. It is so arranged on the secondary side that two transformers can be operated in parallel and independent of the other sets, simply by opening the sectionalizing switch in the high-tension bus bar.

The scheme which is used by the Ontario Power Co. at Niagara Falls is shown in Fig.17. The generators have selector switches and can be connected to either set of low-tension busses or to the primary of the transformers, or else all three connections can be made at the same time, thus tieing the two low-tension bus bars in parallel and feeding the transformers therefrom. The transformers are connected to the high-tension bus bars thru switches. The high-tension bus bar is sectionalized and supplies the feeders thru switches. We notice a similarity to the scheme in Fig.16, the only exception being the addition of a low-tension bus bar which makes it more flexible. Then since low-tension feeders are supplied from the Niagara Station a duplicate bus allows this part of the low-tension to be isolated from the primary of the transformers which may require a different voltage than that on the feeders. Then again, those generators for low tension service normally can be connected to the low-tension feeder, and

when the low-tension load is low can be made to help out on the primary side of the transformers when it is necessary.

A system such as the one described, is found to be the most flexible one in operation. It can be operated on an individual-plant basis, or the generators can be operated in parallel and the transformers operated as individual plants. This system aids very much in the operation of systems which have different kinds of loads, so that a feeder having a low power factor on which there is line trouble can be isolated from the other feeders and assigned to its own generator thus maintaining better service on the rest of the system.

In Fig.18 the primary circuit is similar to that shown in Fig.17, but in the secondary circuit we note the use of a selector switch in the feeders, which makes it possible to operate the feeders in parallel or as independent stations. The whole system can be operated as two independent stations. Assuming that little trouble can occur to the low-tension bus bars the system is all right.

The scheme shown in Fig.19 is used by the Grand Rapids and Lake Michigan Railway and is advantageous in respect to cost of operation since no switches are used on the feeders. All switching is done on the low-tension side of the transformers.

The scheme of Fig.20 is used by the Hudson River Power Co. at Spier Falls and is somewhat similar to that in Fig.18; the only exception being that there is a duplicate set of high-tension bus bars and the low-tension bus bars are sectionalized.

METHODS OF METERING.

Now the methods used in measuring the various phenomena in the circuits will be dealt with. In this section only the situation of the instruments with relation to the main circuits will be dealt with, while the requirements, location, etc. will be treated later. The instruments will be divided into classes with regard to the quantities measured as follows: Voltage, Current, Power, Energy, Frequency, and Power factor.

Voltage.

The voltage is generally measured by having a voltmeter permanently connected to one phase of the bus bar. We have seen from the previous section that in a number of cases two sets of bus bars are used. In this event a voltmeter may be connected to each set of bus bars or a plug may be used to throw the voltmeter to either set of bus bars depending upon which set is used. This latter method avoids the use of an extra voltmeter and on the whole possesses nearly all of the advantages of the first mentioned scheme. As regards the use of voltmeters where the bus is sectionalized, little can be said in general. There is a slight tendency now to run plants on a unit system, but at present there are very few central stations in which this is practiced. The New York Edison Co. operate normally in two units and this would necessitate the use of another voltmeter on the bus bar provided each generator was not provided with a voltmeter. The general practice in stations of average size (2 to 5 generators) is to have a

voltmeter which may be connected on to any generator. This is probably all that is necessary if the voltage of the bus bar is measured and all units are tied to this. However, in some central stations a voltmeter is permanently connected to each generator. This adds additional equipment and in the majority of cases is not advisable. In some cases there is provision for putting the voltmeter on any phase of the bus bar or generator but this is done only to meet some condition of unbalanced load.

Occasionally a voltmeter is put on the feeders but the advantage gained is small where the voltage of the bus bar is measured.

Compensated voltmeters, which measure the voltage at some distant point on the line, are not in common use as they are not very reliable. They depend upon a definite ratio of the resistance and inductance of the line, and hence do not read correctly when this ratio changes.

Current.

The method of measuring the current is not so well defined as is the method of measuring the voltage. To begin with the generators: we find it customary to put either one ammeter or an ammeter per phase in the generator leads; the tendency being a little in favor of the first. Except in rare cases only, one ammeter is needed in the generator leads, particularly in stations of large size where several machines are operated in parallel. Again on transmission systems where the load is

all taken by three-phase receivers(Assuming three-phase generators) the generator phases are balanced. A totalizing ammeter can be used only in rare cases. However, where there is an arrangement as shown in Fig.4,Plate 1,this can be done and is advisable. An ammeter in each phase could be used here to advantage and this is done by the Lackawana Steel Co. on their 440 volt bus bar.

In measuring the current in the feeders it is standard practice to put an ammeter in each phase. The reason for this may not appear evident at first where the energy is taken by a balanced load as rotary converters; however the disturbance in the line is expected from the outside and hence any trouble on one phase will be evident on the ammeters. Ground detectors in this connection will be considered later. We find cases,however,where only one ammeter is used in the feeder particularly in railway central stations. An arrangement is used at the La Chine Rapids Power Co. whereby an ammeter can be connected in any phase of a feeder by means of a plug. The Ontario Power Co. has an ammeter in each delta head of the primaries of the transformers to indicate the current taken by each coil. At the Lackawana Steel Co's.Sub-Station there is a three point plug to throw three ammeters (one per phase) on to any feeder. This enables the operator to get the current in each phase simultaneously and tell the condition of balance on the feeders.

Power.

The measuring of power is essentially done by an indicating or recording instrument, as the time element is not present. We find a great diversity in the use of these instruments. Frequently a recording instrument is used in the generator leads although an indicating instrument on the generator is advisable. The question as to whether this is to be a polyphase or single-phase instrument depends upon the conditions but in nearly all cases a polyphase would be preferable. A single-phase recording instrument would never be used in the generator leads of a polyphase machine. The Ontario Power Co. uses a recording wattmeter in the delta leads of the transformer primaries in addition to the ammeter that was previously mentioned. This gives a complete record of the performance of each coil and is very valuable. The use of power measuring instruments on the bus bars and feeders is not common. In large central stations it might be advisable to have an indicating wattmeter to put on each feeder, where, in connection with the ammeter that is usually there, valuable information as to power factor and output of the feeder could be obtained. This system is used at La Chine Rapids. However, as was stated, it is not done to any great extent. The Hartford, Connecticut Electric Light Co. uses an indicating instrument on each feeder. We find a great deal of confusion between recording wattmeters and recording watt-hour meters in the descriptions of central stations in the Technical Press. In the foregoing, recording

wattmeters only are dealt with, as a recording watt-hour meter measures energy and not power.

Energy.

Energy meters are essentially recording or, better, integrating, as the time element is involved. It is not common to put an integrating wattmeter on the generator, and the information gained is not enough to warrant its use. In small stations we find it general practice to use a totalizing integrating wattmeter to measure the total energy developed by the station. This could not be done in large stations, however, where complicated connections for the main circuits are used. Fig. 4 of Plate 1 shows a method used in the main circuits where a totalizing energy meter can be used very nicely. In large central stations it is customary to measure the energy given to each feeder so that the output of the plant can be determined. The energy consumed by the auxiliaries about the station is usually recorded by an integrating wattmeter.

Frequency.

The use of some kind of a device to determine the frequency of the current is essential, but the operation of the different types of apparatus to determine this is very diverse. The frequency may be determined by an indicating tachometer or by a frequency meter on some part of the system (preferably on the bus bar, as this is nearly always in use). In case of a system where the busses are in duplicate and either is not in use constantly, a switch can be provided to connect the frequency

indicator to either bus or generator.

Power Factor.

Here again there is no standard practice. It is customary to put a power factor indicator on each generator, particularly in large central stations. In small central stations with an arrangement as in Fig.4, Plate 1, it is customary to get the power factor of the system by putting an indicator on the bus bar. Occasionally a power factor indicator is put on the feeder. In the case of synchronous motors it is essential that the power factor of the supply be indicated but this is usually done at the motor and not at the station. As the rotary converter is a synchronous machine the same applies to it.

Graphic Recording Instruments.

The use of graphic recording instruments is not very extensive, but the advantage gained by their use would more than compensate for the expense of their installation. The reason for the lack of their use is probably twofold: first the lack of reliable line except in the past few years; and second the trouble in replacing the records. The location of faults can be greatly aided by the use of such instruments as the condition of all the circuits is known when the fault occurred. They are used extensively by the New York Edison Co. and the Ontario Power Co. The Ontario Power Co. uses them for voltage current, power factor, frequency, and to indicate one minute peaks.

METHODS OF SYNCHRONIZING.

When two or more generators are installed in a central station, some means must be provided for synchronizing them. It is customary in central stations of small size to use a plug and one or more lamps for this purpose. This is done by connecting one phase of the apparatus to be synchronized to the corresponding phase of the apparatus already running thru lamps and a plug. The use of some style of synchroscope that indicates whether the machine "coming in" is too fast or too slow greatly facilitates the operation, and is almost exclusively used in larger central stations. The method of regulating the speed of the generator to be synchronized is of considerable importance. In steam turbines this is frequently done by a motor attachment on the governor of the turbine. On reciprocating engines a small motor or weight actuated by a magnet is used on the governor. At the Kingsbridge Station of the Metropolitan Street Railway Co. the free air exhaust is throttled by a pneumatically operated gate valve controlled from the switchboard. This changes the mean effective pressure in the cylinder and therefore the speed. As nearly all water wheel governors are electrically operated it is easy to put in a control circuit for the purpose of synchronizing, and we find this to be the general practice. This is often carried further so that a unit can be started and stopped from the switchboard. It seems advisable that a synchroscope should be used in addition to lamps where there is much synchronizing to be done

as it is difficult to tell from the lamps which machine is running fast or slow. However lamps are very satisfactory in addition to the synchroscope.

EXCITATION.

The supply of current for exciting the fields of the alternators is most important. Where the continuity of service is of vital importance it becomes necessary to take special precaution in the manner of supplying this current. In small central stations the supply is usually furnished by one steam, and one or more motor-driven exciters. The motor-driven units are for normal service, and the steam units for reserve. In hydro-electric plants the exciter is either on the shaft of the main wheels or else it is driven by small turbine wheels. In large central stations, particularly for the lighting of large cities, it is customary to put in a storage battery as a reserve for excitation and control purposes. This battery is usually located in the basement, although one case was noted where it was placed in the gallery.

The motor exciters are usually induction-motor driven and this system necessitates the use of some form of starter usually located on a panel of the switchboard. As was stated in the methods of metering, the energy used by the auxiliaries is usually measured and the instrument for this purpose can be put on the motor panel. The exciter panel usually accommodates only one exciter and contains a field switch, field rheostat, a main switch, and a volt meter. In the majority of cases the exciter generators are compound wound and this necessitates an equalizer switch if they are to be paralleled. The usual practice is to carry both exciter bus bars along behind the

generator panels, although sometimes only one is carried there, the other being always in circuit and run in conduit. The first mentioned scheme is preferable. Occasionally the exciter bus bars are in duplicate.

The generator panels have a field switch and field ammeter in nearly all cases. The voltage of the exciter bus is sometimes measured by a voltmeter on a bracket where it can be seen from any generator panel. If this is done, only one additional volt-meter which can be connected to any exciter need be supplied for purposes of paralleling. These instruments must be very accurate because if an exciter, the voltage of which does not equal that of the bus bars, is connected to the system, there will be a surge of current which will cause considerable disturbance in the main circuit. Sometimes a low-scale differential volt-meter is so connected as to read the difference between the voltage of the bus bar and the exciter to be connected thereto. In case batteries are used as a reserve, they are floated on the bus bar.

REGULATION.

Current.

Current regulation is confined exclusively to arc light circuits where a constant current is necessary. There are two types of constant current regulators: one being known as the constant current transformer made by the General Electric and Westinghouse Companies, and the other being the constant current regulator made by most of the companies in the market. In all cases it is necessary to install a regulator of some kind on series arc circuits as no constant-current alternating-current generators are in commercial operation. This regulator may be installed in each circuit or various combinations may be obtained to balance three-phase circuits. The connections to the arc circuits are usually made thru plug switches on what is known as a plug board. A short-circuit switch is also provided for each circuit. It might be mentioned here that a special plug is provided to insert an ammeter in the circuit for the purpose of the checking of the action of the regulator. The regulator if single-phase may be either on the line side or generator side of the plug switch, but, in case of a three-phase regulator, it is always connected to the bus bar by a separate switch.

Voltage.

In small stations the regulation of the generator on low power factor is poor, and, in case incandescent lights are supplied from these, it becomes necessary to have some method of

voltage regulation to offset the reduction as the load is increased. This does not apply in large central stations where large units are used as their regulation is good, usually not more than 4% on unity power factor and 6% on .8 power factor for 25% overload. Upon looking over the list of plants using regulators we find that the units are usually about 200 to 300 K.W. An exception to this rule is in the Twin City Rapid Transit Co. of Minneapolis, Minnesota, which has 3500 K.W. generators, and uses a Tirrill regulator. The regulation of these generators however is 12%. There are three general types of regulators in use: namely, the Stilwell, Tirrill, and Induction regulator. The first type is merely an auto-transformer with a movable contact on the line side. The Induction regulator is an auto-transformer which depends for its regulation upon the relative position of the coils or the position of the core, which is sometimes movable. The two types just described are hand operated, and are not used nearly as much in central stations as is the one to be described now. They are used more to regulate the voltage of one feeder of the system rather than the bus bar.

The Tirrill regulator regulates the voltage of the supply by the automatic changing of the excitation. Its operation for one generator and one exciter can be seen by a reference to Plate 3. The alternating current winding of the regulator consists of the pressure circuit, B, taken from the bus bar usually, and wound around the magnet, D. This magnet is also

provided with a series winding, A, which is adjustable, and which tends to compensate for line drop. The core, C, of this magnet is fastened to an arm which is pivoted at E and any motion of this core is balanced by a counter weight, G. This is the only action of the alternating current; the remainder is caused by the direct current control circuit. When the contact at F is closed it energizes the winding on the right hand side of the relay, H, thereby closing the shunt on the exciter rheostat, the relay, H, being differentially wound. Also when F is closed it shunts the winding of the relay, J, thereby causing F to remain closed longer and give the remainder of the apparatus time to act. Thus, when a load is thrown on to the system, the voltage tends to drop; this weakens the magnet, D, and causes its core, C, to drop, closing contact, F. This in turn allows the armature of the relay, H, to drop back, shorting the exciter field rheostat and causing the exciter voltage to rise, thus raising the line voltage. In case several generators are operated from the same bus bar with their exciters in parallel, one regulator will be sufficient to regulate the voltage, but in case either the generators or exciters are operated separately, one regulator for each separate unit is necessary. A separate panel on the switchboard is usually installed for each regulator, and it is desirable to place it as near the exciter panel as possible. The General Electric Co. in its bulletin advises the use of brackets at the end of the switchboard if a panel is not to be used, and say that a regulator should never be placed on the sub-panel.

In the above mentioned publication there are charts showing the results obtained by the use of a type TA(TIRRILL)regulator which show it to be very good for voltage regulation. A disadvantage of this regulator is, that it regulates the voltage of the whole system and cannot be used to regulate the voltage of a single feeder leading from the system.

BUS BAR CONSTRUCTION.

The method of supporting and enclosing the bus bars is to a large extent dependent upon the conditions in the plant. The style of switches is also a determining factor. For instance, if the switches are to be hand operated from the back of the board, the bus bars are nearly always not enclosed and are hung on insulators supported either on the switchboard or on iron framework back of the board. The shape of the bus bar is not of very great importance. The usual shape for comparatively small currents is circular cross section, while for lower voltages and greater currents strips are used. The use of a hollow bus is resorted to in a few cases. The copper on the inside of a solid conductor is to a certain extent wasted, due to the skin effect of the alternating current. The Niagara St. Generating Station at Buffalo, New York, uses this system. It is almost a universal practice to use copper. One exception only was noted at the Snoqualmie Falls Power Plant in Washington. The use of compartments for the enclosure of bus bars is extensive, particularly where oil switches are used in compartments. The practice is, however, very different in different plants. As a rule, for voltages above 26000 or 33000, the bus bars are located in a separate building usually above the transformers and are not enclosed at all and often times are not insulated. The insulation, if used, is more for a protection against fire, dust, moisture etc. than to insulate the wire electrically. The Niagara Falls Power Co. uses

asbestos covering. The reason for not enclosing these very high voltage bus bars is probably because the space overhead in the transformer room affords ample room for the location of them and does not call for additional expense of the compartment construction. Also the high voltage wiring is not complicated, usually consisting of one or two feeders and one set of bus bars, and the transformer leads with only an oil switch in the transformer and feeder leads and sometimes not this. Exceptions to this rule are found, however, but some particular condition requires this additional expense. Ralph D. Mershon goes so far as to advocate the placing of high-tension busses out doors and no serious objection can be found with this, except in severe climatic conditions.

In cases, however, where the main wiring is at all complicated and space is limited by the price of real estate, the use of compartments for the main wiring is advisable for voltages above 2300. The materials used are brick and concrete for the compartments with alberine or slate slabs for supports. The usual practice is to put the bus bars in a vertical row near a wall so that only three sides have to be built. The construction shown on Plate 4 is in use at the Chelsea Generating Station of the London Underground Electric Railway System. The perpendicular walls are of brick while the barriers between the phases are of some suitable stone. Observation dorrs are put in the wall where the bus bar is supported on insulators. These insulators are fastened on the back wall.

In case of a connection to the bus bar a stud is extended thru a bushing placed in the wall of the compartment and the connection to the cable made on the other side.

Cases are frequent where the insulators are secured to the bottom barrier by means of suitable supports. In the past two or three years the use of reinforced concrete for bus bar compartments has become quite common. It is cheaper and quicker to build than brick and does not absorb as much moisture. Its insulating quality is as good as alberine, slate, or soap stone and it is much more convenient to construct. One of the first attempts at this kind of construction was at the Missouri River Power House of the Metropolitan Street Railway of Kansas City, Missouri. The compartments are built of concrete slabs reinforced with barbed wire. The bus bar cells are 14"X14" on the inside. The voltage here is 6300. The location of these compartments with reference to other apparatus will be taken up more in detail later.

The generator leads are usually taken thru the engine room floor directly from the generators and lead to the generator oil switch either in a compartment or in a run-way constructed on the ceiling of the basement. The latter affords sufficient protection if there is no danger from moisture or water in the basement. This practice is almost universally followed out for all generating voltages in this country.

The location and construction of the feeder leads depend upon whether the feeders leave the building overhead or underground. In the former case they usually go up the building wall and leave under some form of hood for protection against the weather. The form of tube used where the feeder goes thru the building is of considerable importance where high potentials are used. Some form of terra cotta or ordinary sewer pipe with a glass diaphragm at each end pierced in the center for the wire is very satisfactory. A large sewer pipe of this kind is used by the Shawanigan Falls Power Co. At the Niagara Falls Power Co., where the wall is brick, two glass plates are set in the wall 2" apart and held here by a separator of some insulating material. This is shown in Plate 8 which is a cross section of the high-tension bay.

In case the feeders are fed underground the potential is not above 11,000 volts as a rule and therefore very high insulation is not necessary. The leads are usually carried the same as the generator leads. The New York Edison feed the sub-stations by four routes, one or more feeders to each sub-station going by each route.

SELECTION OF SWITCHES.

We have seen in "The Connections of the Main Circuits" the proper places in the circuit for switches and will now consider the type, size, location, operation, and construction of the various switches used. The classification of switches as given by Mr. H.C. Smith prepared for Mr. Rushmore for his paper on "Power Plant Connections" given before the A.I.E.E. May 21st. 1906 is complete and appears on page 27A.

A switch must be capable of withstanding the electrical stresses as regards insulation, must be able to carry the current and be able effectually to open the maximum current on short circuit. In the class of circuits we are dealing with the only switches to be considered are oil switches and disconnecting switches. It might be asked here under what head do circuit breakers come? In general, circuit breakers are held closed by a tripping mechanism against the force of some opening device such as a spring or weight. Hence some so-called switches herein dealt with really come under the head of circuit breakers but will be considered here and in the methods of protecting the circuits as switches.

The reliability of the oil switch has been amply demonstrated in the past few years and the development of high tension transmission probably owes a great deal to the progress in this line. Practically the only use of disconnecting knife switches is where they are to be opened when no current flows, as for isolating oil switches, sectionalizing bus bars, etc.

SWITCHES and RELAYS

Break
- Air
- Oil

Methods of Operation.-

- Manual
  - On Panel
  - On Wall
  - On Flat Surfaces
  - Remote
    - In Cell
    - On Pipe Framework
- Electrical
  - D.C. Motor — 3 Forms
    - Std. Sw. [illegible] Mechanism
  - Solenoid
    - D.C. Standard Mechanisms
    - D.C. Special Switches
  - Without Fl. Trip
- Mechanical
  - Pneumatic
  - Float
  - Press. [illegible]
    - Air
    - Liquid
  - With Fl. Trip (See below)

Without Elec. Trip.
- Series Direct Relay Trip — A.C. Trip — With or Without Time — Constant / Inverse — Overload
- Without Current Transformers
- Auxiliary Trip
  - Push Button
  - Low Voltage — With or Without Neutral Transformers or Series Resistance

With Elec. Trip.
- [illegible] Mounted in [illegible] [illegible]
  - Without Direct Relay Trip A.C.
    - On Panel
    - On Shaft
    - Overload — A.C. Trip / D.C. Trip
    - Reverse Current — D.C. Trip / A.C. Trip
- With Current Transformers
  - Without Time (Instantaneous)
    - Reverse Phase — D.C. Trip
    - Differential — D.C. Trip
    - Low Voltage — D.C. Trip
  - [illegible] Time Element — With Relay
    - Under Load — A.C. Trip
    - With Time Constant Element or Inverse
      - Overload — A.C. Trip / D.C. Trip
      - Reverse Current — D.C. Trip

Attachments.
- Auxiliary Switches (Circuit Opening)
- Indicating Switches (circuit closing)
- Interlocks
  - Electrical
  - Mechanical

The oil switch is one in which the circuit is broken under oil. This method tends to disrupt the arc formed and the oil itself forms a very good insulator for the parts. Oil switches are of two general types; horizontal and vertical. The horizontal type uses less oil than the vertical but the oil is liable to be blown out while no case is on record where the oil of a vertical switch was blown out on opening the circuit even under the most severe conditions. Oil switches for voltages up to about 3000 volts are made in hand-operating types and may be mounted directly on the back of the switch-board or an iron framework. The latter is preferable because no matter how well protected the oil is it is liable to spread to the marble panels and disfigure them. These switches are made automatic or non-automatic as is desired. They are built in single-pole elements and in case more than a single-pole switch is desired the single-pole elements are connected to one control handle which operates all simultaneously. Further description of this class of switches is unnecessary.

For potentials above 3300 volts usually large oil switches built in brick compartments are used; namely, Type C made by the Westinghouse Electric and Manufacturing Co. and Type F, Form H, made by the General Electric Co. The essential difference between the two is in the method of operation. The Type C is solenoid operated and the Type F, Form H, is motor operated. Each is composed of single-pole elements with two breaks and are built in separate brick compartments. If more

than a single-pole is required they can be grouped as in the previous case.

The Type C is made in standard sizes for 45,000 and 60,000 volt circuits. It was some years ago common practice to break these very high potentials in air by specially designed switches, but since the advent of improved oil switches they are not used now. These high-tension Type C switches also are made in single-pole elements with double break. The U-shaped element which closes the contacts is connected to a specially treated wooden handle which in turn is connected to the operating mechanism. It is operated by a solenoid mounted on top of the switch. The oil tank is of rectangular shape of copper fitted with a masonry cell. The copper tank has a bottom of treated wood and a framework on the sides also. This framework supports a second lining which is of alberene stone and covers the entire surface. There is a double barrier of similar material between the poles. The wooden rod previously mentioned carrying the contact piece is between these pieces. The connections are led out in porcelain brushings for quite a distance. It is desirable that all oil switches be provided with disconnecting switches so that they can be isolated for repairs. The standard operating voltage for these types is 125 volt direct current. This supply must be provided for by an addition to the capacity of the exciters, storage battery, etc. We shall now consider the different kinds of switches. They may be grouped

as regards their use as follows: generator, selector, transformer, bus bar tie, sectionalizing, group, feeder, and disconnecting switches. There is some controversy as to the advisability of having two switches in series as a safeguard in opening the circuit; but the reliability of oil switches is such that this is hardly advisable.

The generator switch is in the line from the generator to the next piece of apparatus and its opening isolates the generator from the other apparatus. It must have a carrying capacity equal to the two-hour overload capacity of the generator. It must be able to open the short circuit current equal to the combined capacity of the remaining generators on that part of the system providing the bus bar sectionalizing switch is not to be opened first. In this event its opening capacity need only be that of the generators left on its section of the bus bar. The location of the generator switch depends upon the rest of the switching apparatus. As was stated previously, in smaller Central Stations, where the voltage is 2300, the switches are usually on the back of the switchboard or on iron frame work just back of the switchboard. The latter is much better but considerable space should be left between the switchboard and the switch as a means of protection to the operator. In the case of large stations, there seems to be no general practice as to the location of these switches. Preferably they are close to the bus bar compartments so that they can be built right into this structure.

A selector switch, as the name implies, is one to connect the source of power to either of two or more outlets, usually two. Thus it can be used in connection with generators, transformers, or feeders. This can be either a double-throw switch or two single-throw switches; preferably the latter. They may be knife disconnecting switches where they are not to be thrown under load. A scheme is used by the Shawinigan Falls Power Co. that is a very good one, as far as reliability is concerned, and is comparatively cheap. As seen in Plate 7 the main generator oil switch must be opened before any of the disconnecting switches can be closed, and also the disconnecting switches must be closed, on one bus before the generator oil switch can be closed. In cases these selector switches are oil switches the operation of each can be tested before they are both closed. The one which is not automatic is used for synchronizing. If these switches are knife disconnecting switches the problem as to where to put them is difficult. It is not desirable to lead the high-tension to the switchboard. It is probably best to locate the switch on the bus bar structure near the generator switch.

Transformer switches are used on both sides of the transformer. Their rating is on the two-hour overload capacity of the transformers. In case the transformers are delta connected, sometimes a delta switch is put in the high and low-tension side of each coil to isolate a bad transformer.

These are located either on the structure of the compartment or near the transformer on a small panel. These switches are operated on no load and can be knife disconnecting switches. This practice is not common as nearly all transformers for this purpose are star connected.

Line switches are subject to the most severe strains and are of first importance. Most of the disturbances in a plant are due to trouble on the outside and it is essential that this be cut off if serious enough to endanger the apparatus inside. The line switch must be able to open the circuit when maximum power is being delivered from all the generators on that section. However, it is sometimes desirable to leave the trouble on temporarily in the hope of burning it out where continuity of service is of enough importance. In case of automatic sectionalizing switches the line switch will have less to open than otherwise. The capacity of the line switch is in accordance with the two-hour overload of the generators and it must be able to open the total capacity of the generators on that section of bus bar.

Sectionalizing switches are nearly always long-break hand-operated knife switches. The exception to this is where a buss sectionalizing switch is used to cut down the capacity on short circuit, and here an automatic oil switch is used. The location of the knife switches is usually on insulators right in the compartment. The bus bar sectional-izing switches used by the New York Edison Co. are on insulators.

and a glass plate is put into compartment wall so that the position of the switch can be seen from the outside.

The location of switches and bus bars is so closely connected and depends upon conditions to such an extent that the description of three or four special installations will probably be of more information than a general discussion.

Plate 4 shows the bus bar and switching arrangement in use at the Chelsea Generating Station of the London Underground Electric Railway System. The connections of the main circuits are similar to those shown in Fig. 2, Plate 1, except that there is only one set of bus bars. The generator cables are carried under the engine room floor to a point under the generator oil switch, A, then up a brick wall thru a series transformer, B, and up into the oil switch on the first mezzanine thru a bushing in the floor. From the oil switch the lead passes in a horizontal brick compartment to a wall back of the switch and up this wall to the disconnecting switch, C just under the floor of the second mezzanine. Then the lead passes up thru this floor to the main bus bar, D. The arrangement of these connections is shown in the [illegible] view. The bus bars are in a vertical row in compartments. The walls of these compartments are brick with suitable barriers between the phases. The inside dimension of each compartment is 18"X18". The bus is supported in the center of each compartment on insulators fastened to the back wall of the compartment. The bus sectionalizing switch, E, is an oil switch and is on the floor of the second mezzanine and nearly in line with the bus.

From the bus bar the lead goes up thru a disconnecting switch, F, to the feeder group switch, G, on the third mezzanine to the feeder group bus located in front of the feeder switches. This bus bar is in a compartment similar to that of the main buss. The feeder now goes to the feeder switch located in line with the feeder group switches from which it goes down thru a series transformer and a lightning arrester provided with a disconnecting switch and located in line with the panel, J, shown in the cross section. The three cables then enter one three-phase cable in a large pot head supported on the rear of the above mentioned panel. The feeder cable now goes down thru the two floors to the outgoing conduit. The clamps, K, show the method of supporting the cable to relieve the tension on the pot head. These cables are three-core paper-insulated, lead-covered cables of the standard English pattern. They are tested at the factory with 33,000 volts and with 22,000 after being installed. This represents a typical installation for a large plant where there are no transformers used.

The use of galleries is common in this type of plant they being used by nearly all the large companies where these conditions obtain. The New York Edison Co. uses six galleries in the new Waterside Station No. 2 along the entire 40th. St. side. On the first are the main and auxiliary busses in cells of brick with alberine partition construction. These compartments have wired glass doors where the cables connect to the bus bars thru disconnecting switches. On the second

mezzanine are the selector switches while on the 4th. mezzanine are the feeder switches. The instrument transformers are on the 3rd. mezzanine and the feeders are brought down from the 4th. mezzanine to the outgoing lines.

We will now consider the equipment of a plant where galleries are not used, as exemplified by the Twin City Rapid Transit Co. of Minneapolis. They do not use transformers and the one bus is divided into three sections by means of oil switches. Each oil switch is provided with two disconnecting switches. The generators feed to the bus bar thru an oil switch and a disconnecting switch and the feeders are fed thru a disconnecting switch, oil switch, and disconnecting switch in order. Reference to Plate F shows the generator leads carried under the floor to a point under the oil switch and then up into the oil switch, A. From there they go thru a compartment, B, built of brick, on the main engine room floor to the wall of the bus bar compartment, C. From there a lead goes thru a disconnecting switch to the bus bars in compartments. These compartments are built of brick with concrete anchorage for the insulators and concrete barriers. From the bus bars the leads go to a disconnecting switch, D, on the back of the compartment, then down and in a similar compartment to that of the generator leads to the feeder oil switch, E, then down and thru another compartment to the wall of the building where they rise and go thru another disconnecting switch, F, at which point the lightning arrester, G, is tapped off. Then

the feeder cables bend back and enter a pot head, I, for the out going cable.

The bus sectionalizing arrangement is shown in the front view. The bus bar rises into the compartment above and goes thru a disconnecting switch at A then down and thru the oil switch, B, and back to the other section of the bus thru a disconnecting switch at C. The figure shows the important dimensions. This system is used quite extensively, particularly in water power plants where floor space is not an important factor.

We will now consider the arrangement of apparatus in the high-tension bay of the Ontario Power Co. Referring to Plate 6 we see the line entering on the upper right hand side at A, and bending down and thru the series transformer, B, thru a disconnecting switch. It then loops over to the high-tension transformer oil switch, C, which is of the Westinghouse Type C pattern. Then the lead goes up thru a disconnecting switch, D, mounted on a channel iron, and up to the high-tension busses, EEE, which are mounted on insulators supported on steel pins fastened to channels. From the high-tension busses the feeders loop down to the disconnecting switch, F, feeder oil switch, J, up the wall and out on the line thru the aperature at K.

The three systems just described give a fairly clear outline of what is done in the location and construction of the main switching apparatus and while several more illustrations could be given we believe that the information gained is not

sufficient to warrant further investigation along this line. The object sought in all installations is to obtain reliability, flexibility, and convenience at the least possible cost and the conditions are so widely different that no standard can be made.

PROTECTIVE DEVICES.

In taking up the discussion of protective devices we wish to consider the two general classes which are being used; namely, lightning arresters for the protection of circuits against lightning phenomena, and the numerous types of relays which are used to protect against excessive or reverse currents. Since the latter class of apparatus is so closely related to the operation of automatic switches we wish to take up the treatment of protective devices at this point.

The apparatus for protection against lightning is designed to operate without interruption to the service, while the overload and time-limit relays always operate in such a way that the service is interrupted. In the first case the apparatus in the central station is subjected to abnormal voltages and abnormal frequencies, and the strain is relieved by a static discharge taking place thru the arrester. In the latter case, however, the apparatus in the station is subjected to current of such a value that excessive heating would result if the circuit were not opened by some automatic device.

Relays.

The use of relays in connection with automatic switches is an absolute necessity in Central Stations having a great many generators and feeders. When trouble occurs on one feeder, or a short circuit comes on a generator, it is very desirable that this circuit be isolated from the system at once. However, it is not desirable in the case of overloads to have

the feeder opened if the overload is due to a swinging load of short duration, since the danger from the excessive currents is dependent on the time they flow. Also, when the generators are being synchronized it often happens that the machine is thrown in, out of step, and a surge of power from the bus bar to the machine results. In this case it is desirable to have a device for automatically disconnecting the generator instantaneously. This surge of power to the generators may also occur [illegible] parallel operation [illegible] time as the [illegible] power [illegible]. Again, in the case of feeders, it is essential that there be a device on the receiver so that in case trouble arises here the receiver can be disconnected first, then the feeder, and finally the generator, if the trouble is serious enough to warrant this.

These [illegible] classes of trouble call for the following [illegible] relays; namely, overload, reverse [illegible] [illegible]. The time element [illegible] [illegible] can be instantaneous, inverse, or definite, and the relays [illegible] operate so as to close a direct current control circuit to the automatic switch or to open a circuit with a series transformer giving alternating current for the control of the switch. The types of relays will be taken up in the order named and their operation and location explained.

The overload relay is used on generators and feeders and has the inverse time element except in case where the fire risk

would be too great. The idea in having the inverse time element is that the trouble on the circuit if like a swinging load will last only a short time as a rule and it is not advisable to shut down the system. The inverse time element is introduced mechanically by means of a bellows, which discharges air at a certain rate, or a dash-pot attached to the solenoid. The ampere-time curve taken from a bellows type inverse time element relay is shown in Plate 8. Reference to this curve shows that the greater the current, the less the time required for the solenoid to complete its motion and trip the breaker.

Overload relays made by the Westinghouse Electric and Manufacturing Co. have the definite time element. By means of dials and pointers, either the time or the overload can be adjusted so that at a given overload the trip coil of the automatic circuit breaker will be operated if the overload lasts for a pre-determined time. If the overload does not continue for this pre-determined time, the relay returns to its normal position. The relay is connected to the circuit by means of series transformers and is made to be used in connection with oil circuit breakers where the trip coils are operated by 10 to 500 volt direct current circuits. These connections are shown in Plate 9, Fig. 1. The definite time element is necessary because it is not advisable to open a switch during the high frequency oscillations due to a short circuit, since the oscillatory power would cause an arc to start between the terminals of the switch. The time element, therefore, gives

the oscillations time to diminish. Also, the definite time element may give a short circuit time to burn off if not too heavy.

This type of relay is placed on generators and feeders. However, in the former case it has been recommended that the switch be non-automatic, while in the latter it is essential that the arrangement of the time elements be adjusted so that the receiver will be disconnected first and then the next higher circuit. This, then, saves a shut down in many cases. Plate 10, Fig. 1, shows the connections for the General Electric Co's. overload relay operating a direct current control circuit.

The reverse current relay is used extensively on generator and feeder switches to take care, automatically, of such trouble as failure of excitation or prime mover, or of synchronizing. It must therefore operate when the flow of energy reverses. At first this type of relay gave trouble in the case of short circuits, since it would not operate on low voltages. Then at low power factors there was little torque to operate the relay which was of the induction type. However, we now have a reverse current relay made by the Westinghouse Electric and Manufacturing Co., which seems to give satisfactory results. It has been installed at the Ontario Power Co's. Distributing Station and several of the largest central stations in this country.

Its operation can be explained by reference to Plate 9,

Fig.8. There are two electro-magnets which rotate two discs mounted on the same shaft. The mechanical construction is very similar to that in the Westinghouse Type,C,Polyphase Integrating Wattmeter. The motion of the discs in the relay is controlled by means of a spring. A moving arm closes the control circuit at the key,K. In case the control circuit requires more than one ampere the key,K,closes a circuit to an auxiliary relay with contacts which close the control circuit. The coils are effected by voltage, current, and true watts. The relay operates on low voltage or low current since the torque is large for low power factors. The inverse time element is accomplished by the damping effect on the disc, and can be adjusted.

The General Electric Co. manufactures a differential relay which is intended to accomplish the same results as those required of a reverse current relay, but we have found that this type of relay has given serious trouble and caused unnecessary shut downs. A wiring scheme of the relay is shown in Plate 10. Fig.8. As can be seen the solenoid flux is interlinked with two electrical circuits: one from the current transformers, and one from the potential transformers. These circuits act in opposition, and their resultant field under normal conditions is zero. Now if the magnetomotive of one winding exceeds that of the other, the relay will be affected, since a flux then acts on the solenoid. Again when the current reverses the action of the two coils of the relay is accumulative and the relay closes the direct current control circuit to the oil

switch. In synchronizing, of course, there is but one coil energized since very small current flows in the generator leads, and it has been found that the plunger of the relay will vibrate on low frequency, thereby introducing a bad feature. We therefore do not recommend the use of differential relays.

Reverse phase relays are of the instantaneous time element type and are made to disconnect a motor in case it has been improperly connected to the line. These relays would not be used in ordinary substations, but their use in the receivers on feeder systems will materially effect the automatic operation of the station.

The use of low voltage relays is recommended where motors are started by means of additional resistance, and where it is necessary to have the motor disconnected in case the resistance is not enough for starting.

The above mentioned relays all operate on the circuit-closing principle; that is, the relay closes a contact when operating and this closes the control circuit to the oil switch. We note the use also of relays of the circuit-opening type where the contact is closed during normal conditions. However, when the relay operates the circuit to the trip-coil which in this case is operated by the current from the series transformers the current is opened and the alternating current allowed to energize the trip-coil. Schemes for these types of connections are shown in Plates 9 and 10. The connections of the relays are practically the same as the circuit closing type

as can be seen from the schemes.

The relays are mounted on the front of the switchboard in all cases. In general, the generator relays are placed on the sub-panel of the generator panel, and the feeder relays are likewise placed on the sub-panel of the feeder panel. However, in the case of the Westinghouse types where the relay cases are designed on lines similar to the instruments it looks well to place the relays on the upper panel. At the Ontario Power Co., the relays are all placed on special terminal panels on the second floor of the control chamber. In this case the ultimate capacity of the station will warrant such an expenditure for separate panels. In addition, however, these panels contain fuses for each wire of the auxiliary wiring for the generator control.

We have some cases where a hand operated switch is supplied with a toggle joint which is tripped by means of a relay. In this case the relay is installed just underneath or at the side of the switch handle.

Lightning Arresters.

Abnormal voltage and abnormal frequency produce a strain in the insulation of insulators, switches, transformers, and generators, and the point at which the lightning arrester should operate is determined from the dielectric strength of the insulation of these various pieces of apparatus. For insulators the permissible strain is 300% of the normal line voltage; for switches it is 250% of the line voltage; for transformers it is independent of the method of connecting,

and is about 200% of the normal voltage, between coil and core and for generators it varies from 150% of the rated terminal voltage for 50000 volt machines to 250% of the rated terminal voltage for 400 volt machines. Hence the permissible rise of potential is less than 100%, and about 60% of the line voltage seems to be the point at which the arrester should operate.

Up to the present time a great many conclusions have been drawn from data which have been obtained from numerous installations of lightning arresters, but it seems that these data are insufficient to aid in deciding on the most efficient type of arrester in operation. At first it seemed that a certain arrangement had proved successful and when about to conclude that all data showed this, something new and unexpected would be observed at the next lightning disturbance. Hence it appears that most of the attempts to protect against the phenomena have been guesses. Since the action of the lightning is so variable and its force so great that it is beyond all control, it is impossible to experiment with it and all we can do is to decide by observing the phenomena in practice.

From the fact, that the point of operation of the arrester depends upon the dielectric strength of the insulation of the apparatus to be protected, it seems reasonable to suppose that great benefit can be derived by increasing the dielectric strength which in turn is secured by the improving of the method of insulation. Also the grounded neutral star method

of connecting transformers on three-phase systems offers a condition which is recommended as an aid in protection against the disturbances of lightning. The strain on the insulation between the coils and the core is decreased in the ratio of 3:1.

Some recommend the use of a choke coil between the line and the apparatus. This coil is often made of the line wire wound into a helix 6" in diameter or is made of special wire wound in the shape of a spiral. The lightning arrester is placed between the line and the choke coil so that the surge will find an escape to ground and never reach the apparatus. However, Ralph D. Mershon, who has had some successful experiences with lightning apparatus, does not recommend the use of the choke coil for two reasons; namely, first, the lightning is often of low frequency as well as high, and it would not be practicable to construct a reactance to prevent the low frequency component from getting thru to the apparatus in the station; and second disturbances are apt to arise when a switch is operated and since this disturbance would be behind the choke coil a strain would result in the insulation of the various pieces of apparatus in the generating system and if sufficient would cause trouble. This could be done away with by putting another set of arresters on the apparatus side of the choke coil, but this would be expensive.

A static interrupter is recommended by the Westinghouse Electric and Manufacturing Co. for diminishing the surge from the line to the apparatus in the station. The interrupter

differs from the simple choke coil in that it has a condenser in series with the reactance, and between the reactance and the apparatus to be protected. The interrupter is connected between the apparatus and its switch so that surges due to an opening of the switch will be damped. This same company claims that the reactance decreases the severity of the surge. However, since it has happened in installations having these reactances in the line that the low frequency surges have passed thru and caused trouble, the chances are that it may do this with any other set of conditions and hence its use would not be recommended. There are installations where the choke coil has been used and no trouble has arisen, but who can prove that trouble might have happened had it not been used?

The arrester itself is connected to the line at a point just before the outgoing line leaves the building. This connection in the Westinghouse Low-Equivalent Arrester is made thru a switch so that the arrester can be disconnected from the line at any time and inspected and cleaned. The switch has a cast iron base supporting two high voltage insulators to which the switch jaws are fastened. The switch is single-pole, front-connected and opened by means of a hook attached to a wooden handle.

The arrester itself consists of a number of cylinders of non-arcing metal, separated from each other by an air gap and placed, in series with a low, almost non-inductive, resistance between the switch and ground. A number of these gaps are

shunted by means of a high wire wound resistance which tends to draw out the arc on the shunt gaps, see Fig. 1, Plate 11. The function of the series resistance, in connection with the shunt resistance after the arc is drawn out, is to prevent the dynamic current from following the discharge for more than one half cycle. The whole piece of apparatus is called a low-equivalent arrester since it relieves the strain on the dielectric of the circuit at a point far below the allowable rise. To determine the rating of the arrester it is placed in parallel with a specially designed needle gap and the distance between the needles is adjusted so that at a given strain the discharge just fails to pass the needle gap. The distance between the sewing needles is then taken as the rating. Since this distance is a measure of the voltage across the gap it readily shows the normal line voltage for which the arrester was designed.

The arrester is provided with an auxiliary gap which can be adjusted until the rating of the arrester suits some special conditions such as the nature of the objects surrounding the arrester, the line capacity and voltage, and the wave form of the generator. When as a station is operated for some time the dielectric strength of the various kinds of insulation used therein becomes less due to constant heating and this necessitates the changing of the auxiliary gap.

A lightning arrester is exposed to high voltage and must

therefore be well insulated from ground so that the discharge will take place the full length of the arrester. The Westinghouse arresters are mounted on marble with a dielectric strength equal to that of high potential switchboards. Marble or brick barriers are built up between the arrester for the different phases to lessen the danger of a discharge between the phases direct.

The value of the arrester depends very greatly on the nature of grounding, which should be done with as few bends as possible. If a suitable ground cannot be found near the arrester, the principal ground should be made at the distant point and an auxiliary ground made directly beneath the arrester to a pipe, and need not be complicated or expensive. The principal ground should be made to a copper plate covered with ground lead and buried in fine charcoal placed in a permanently damp place in the ground.

The General Electric Co. builds an arrester which has no series resistance, this being considered a hindrance to the successful operation of an arrester. The shunted gaps have carborundum resistance in parallel with them, and their number is one half that of all the gaps. An adjustable gap is connected to the knife switch, and then the shunted gaps and the carborundum resistance are connected in. On the three-phase system the arresters from each of the phases are connected together and a number of gaps are placed between this point and the ground. See Fig.5, Plate 11. This type has been

installed by the Aurora Elgin and Chicago Electric Railway Co. in their central station at Batavia, Ill. The reason for the leaving out of the series resistance is that cases have been found in which cylinders of the arrester were melted together where such resistance was used. The Company claims to have had success without it.

Another type of arrester, which seems to be giving as much satisfaction as the above mentioned types, is the horn arrester. This is a single gap, in contra-distinction to the above, which are multi-gap. An example of this type is found at the Ontario Power Co's. distributing station. The arrester is located outside the building on the 60000 volt feeders and each phase is supplied with three. They are connected as shown in Fig. 5, Plate 11. The first gap is 3" with a carbon resistance and ground. This carbon resistance consists of three 3" carborundum rods, 3 feet long, and connected in parallel. The second gap is 3", and has water resistance in series with it. The water is placed in barrels set beside the wooden pole on the top of which the horn is fastened. The third gap is 12" and has a copper fuse 3"X1/8" in series with it.

The theory of the horn arrester is that heat generated by the arc produces air currents which in rising tend to blow out the arc. The field of the arc is at right angles to the field around the horn and this as well tends to break the arc. Perhaps the latter effect is the greater. If one gap cannot

take care of the discharge the next larger in size will offer a second path, and if this is not sufficient the third path will be taken and all three paths acting in parallel offer a low resistance path to ground. If the three paths fail to cut down the dynamic current it will blow the copper fuse on the 12" gap and relieve the strain. It has been found that, where the dynamic current surges to ground, synchronous apparatus is thrown out of step and the service thereby interrupted. Also in trying to synchronize, surges may be started if the apparatus is thrown in, out of step. Hence the necessity for a perfect arrester.

The three types of arresters mentioned here give more or less trouble and have proved unsuccessful in some instances, but since we have found them so generally used, we think it is an indication that they are a great help in taking care of static disturbances. A disadvantage of the last type of arrester mentioned might be that it has to be installed out of doors. However Ralph D. Mershon states that in time we shall find it the practice to install more high-tension apparatus out of doors. It seems reasonable to him that even the bus bars since they are similar to a feeder may be installed out of doors instead of cramped into one corner of a building.

A method which has given almost perfect protection of wood pole transmission lines against atmospheric electricity is that of carrying one or more ground wires above the conductors. These ground wires relieve the static strain on

the line and amount to the same thing as placing the conductors underground. This seems to be the proper method for solving the problem of lightning phenomena due to external disturbances. It keeps out all influences while other methods allow the disturbance to take place and then try to get rid of its effect.

SELECTION OF INSTRUMENTS.

The selection of instruments for metering the currents in polyphase systems has received considerable attention lately and some very interesting conclusions have been drawn. The requirements first for indicating instruments are as follows:

1. Accuracy to within 2% for all conditions
2. Long Scale
3. Dead Beat
4. Sufficient capacity to prevent overloads from sending the needle off the scale.

The accuracy of integrating wattmeters should be even better than 2%. This subject will be treated more in detail later. The question of capacity is of considerable importance. An instrument where the needle is constantly near the zero position is of little use while one of sufficient capacity to allow for all reasonable overloads is necessary. Greater overloads are carried by street railway plants than by lighting plants and hence the necessity for larger capacity ammeters and indicating wattmeters. The usual practice is to have the needle run in at about 1/2 or 2/3 scale for normal operation. The scale on most switchboard instruments for alternating current is not uniformally divided and cannot be due to the principle of operation and hence very low readings are valueless due to the close divisions on the scale near zero.

The errors that readings of instruments are subject to

are as follows:

1. Errors resulting from mechanical causes, as friction
2. Errors resulting from electrical causes, as hipteresis and eddy currents.
3. Errors in calibration
4. Errors in reading, as parallox.

These will now be considered in general in the order mentioned. The friction losses are a very important factor in the selection of instruments. They may cause a 5 to 10% error but with proper care this loss may be reduced to 1 or 2%. This is a constant loss for which compensation may be made. The force actuating an indicating instrument of any kind is less than one thousandeth of a foot-pound, so a very small amount of friction will cause a great error. One case was noted where a certain set of generator wattmeters and feeder wattmeters rarely agreed by 5% and when the bearings were changed to cupped diamonds the error was reduced to 1.5% which shows that the friction should be made a minimum.

A device is used by the Diamond Meter Co. whereby the gear driving the recording mechanism revolves the bearing and thereby keeps it centered at all times. The loss due to friction applies more particularly to recording instruments than to indicating instruments. The quality of the springs used as restoring forces is another factor in the stability of the instrument but little difficulty is experienced now along this

line. The same is true with hysteresis. Some instruments have no restoring forces at all, as some types of power factor indicators and integrating wattmeters. The vibration of the switchboard effects the friction and permanency of the instruments.

The question of stray fields is an important one in the accuracy of instruments. However, as all switchboard instruments are enclosed in a soft iron case the effects are to a certain extent neutralized. The error due to a wire carrying 1000 amperes placed one meter from the case was only .5% on maximum deflection. This is negligible when the usual location of bus bars is considered.

The periodic testing of instruments is the only way to maintain proper accuracy. Some means should be provided whereby this may be done easily. The use of instrument transformers greatly facilitates the calibration since the series transformers are provided with short circuit plugs, and the potential transformers with two disconnecting switches. It then resolves itself into removing an instruments from a low-tension circuit for calibrating when instrument transformers are used. Too little attention in the past has been paid to this feature, and oftentimes it is nearly impossible to remove an instrument for testing. Again, if the instruments are removed and taken into the laboratory under ideal conditions some of the deteriorating effects are removed. The most advisable scheme is to have plugs to insert the standard

instruments into circuit for testing while the instrument is left under normal operating conditions. This scheme is used at the Ontario Power Co's. Distributing Station. The marking of scales must be very accurate or considerable error may creep in.

The various damping methods to obtain dead beat instruments belong to three classes; viscosity of liquids, resistance of air, and eddy currents. The latter is to be preferred as it is very satisfactory and does not include any additional apparatus to increase friction. It is a method too that is almost universally used in alternating current instruments.

The choice of scales and pointers should be given some attention. For very accurate reading the use of a small pointer and mirror is necessary, while for nearly all switchboard work a plain pointer and a scale that can be read for some distance are desirable, as nearly all readings are taken quickly and approximately in a great many cases while the operator is not very near the instrument. The scales on some of the Westinghouse instruments are 14" long and subtend an arc of 300 degrees.

There are various types of alternating current instruments on the market. They can be divided as follows:

1. Induction Type
2. Electrostatic Type
3. Movable Iron Type
4. Dynamometer Type.

Since the electrostatic type is not used at all for switchboard work, we will consider the relative advantages of each of the remaining types. First, we will consider the conditions in the circuit which will affect the accuracy of instruments in general. They are variation of voltage, current, power-factor, frequency, wave form, and any combination of the above.

The induction type is used particularly in integrating wattmeters and is very satisfactory in general and whenever an integrating wattmeter is to be used, it is preferable to use the induction type. This induction principle is also made use of in ammeters, voltmeters, and indicating wattmeters, particularly by the Westinghouse Electric and Manufacturing Co. in their switch board instruments. The induction type of instrument is very little affected by variation in power factor and the wattmeters are fairly accurate for a 10% variation in voltage. The common tendency of all integrating instruments is to read low. Tests have been carried on which show that two to four times as many read slow as fast. This is, of course, due to the damping action of friction and is more particularly true on light loads. The induction type instrument, however, has the disadvantage of varying considerably with frequency, but this objection is obviated to a certain extent because the frequency of a given supply is held fairly constant at all times and these types are provided with adjustable coils to compensate for changes in this frequency. The shape of the wave form affects them also. The presence of higher

harmonics causes the pressure of high frequency currents, and this disturbs the "quadrature" of the currents in the pressure and series coils for unity power factor. It is interesting to note the several ways of bringing the current in series and pressure coils in quadrature. The Ferranti Meter accomplishes this by rotating the series coils. Others secure it by means of short circuited coils on the series core. In general we find the induction type very satisfactory.

Movable Iron instruments are of three types as regards construction:

1. Single moving mass
2. A fixed mass of iron attracting or repelling a moving mass
3. A combination of attracting and repelling irons.

The second class is the most important. The errors in this type of instrument that are not common to all others are traceable to the hysteresis of the iron. This is, however, not present in alternating current instruments. The effect of stray fields is negligible here because of a fairly strong field. The error may be about .25% for a bar carrying 1000 amperes, placed 1 meter from the instrument which is enclosed in an iron case. The shape of the wave form, however, has considerable effect on this type of instrument; sometimes as much as 10%. This can be reduced, however, by using a low flux density and a small cross section of iron in the instrument. The effect of change of frequency can also be kept down if the cross

section of the iron be made small. One drawback that was previously mentioned is very important here; that of the cramping of the scale near zero. The damping of soft iron instruments can not advantageously be accomplished by eddy currents on account of the affect these latter have upon the moving iron, consequently the best way is to depend upon the viscosity of oil.

Dynamometer type instruments were perfected because they could be used equally well on alternating or direct current, and the indications were independent of frequency on alternating current. They are, however, affected by stray fields because of the weak field employed. They require a phase-splitting device when used on alternating current as voltmeters or ammeters.

A few considerations as to the power consumption of the various types of instruments will be valuable as they directly affect the economy of operation. The table below gives some results obtained by Edgcumbe & Punga of England.

Instrument.		Power Consumption.
Moving Iron Voltmeter	200 volts	10 watts
" " Ammeter	100 amperes	3 "
Induction Voltmeter		5 to 8 "
" Ammeter		5 to 8 "
Dynamometer Voltmeter	200 volts	10 "
" Ammeter	100 amperes	50 "

There are three general types of wattmeters in use as follows:

1. Dynamometer Type.

2. Induction "

3. Hot Wire "

The third class is very little used and is not found at all in switchboard use.

The dynamometer type is very satisfactory for accurate work as an indicating instrument but as it necessitates the use of some commutating device on integrating instruments it is not advisable to use it in this connection. The induction type possesses the same disadvantage in regard to frequency, as the induction type voltmeter and ammeter previously mentioned, and hence it is practical only where the frequency is constant. The torque depends almost directly upon the frequency and hence a change from 40 to 60 cycles may mean an error of 15% or 20%. This however can be compensated for so that meters of this type can be depended upon for accuracy to within 1%.

Power factor indicators until very recently were constructed only for two or three-phase work. These were essentially a combination of two wattmeters. The General Electric type has two series coils placed so that they surround a pinion on which are mounted two pressure coils. These pressure coils are so placed that ordinary variations of power factor will give a suitable scale deflection. The Westinghouse Electric and Manufacturing Co. use two series coils and one pressure coil. The power factor is indicated by an iron vane which

takes up a position dependent upon the position of the resultant field. These instruments indicate the average power factor of the system and not that of any one phase. There is a single phase power factor indicator recently placed on the market by the Westinghouse Electric and Manufacturing Co., and it gives fair satisfaction.

The various styles of synchroscopes will be dealt with now. The use of lamps as a means of synchronizing was mentioned previously, and needs no discussion. They are usually mounted on the generator panel near the top accompanied by a suitable plug below the instruments. The use of some type of synchroscope is advisable in the majority of cases. These are indicating instruments similar in operation to power factor meters but more powerful. They will revolve with a speed equal to the difference in speed between the machine to be synchronized and the one already running and if properly connected show which is fast and which is slow. They are usually located in some prominent place if a separate one is not installed on each generator panel. They are made in large sizes with a dial 16" or 18" in diameter when designed to be put on a bracket or on top of the board.

There is an automatic synchronizer made by the Westinghouse Electric and Manufacturing Co., which should give satisfaction if conditions are such that it can be used. Referring to Plate 1[illegible] which is a diagram of the automatic synchronizer we see to the left the two machine circuits connected to the bus

bar. The synchronizer itself consists of two solenoids acting on cores hung on the opposite ends of a rocker arm. The solenoids are so wound that when there is no phase difference or when the machines are in synchronism, the solenoid at the right is down, and when they are exactly in opposition the left one is down. Thus, when one machine runs faster than the other, this solenoid oscillates. The contact for the operation of the auxiliary relay is closed at a pre-determined time before the right hand solenoid is down. The dash pot on the apparatus prevents the closing of this contact if the machines are too much out of synchronism. The auxiliary relay is used to avoid the necessity of carrying the contacts of the main closing circuit to the synchronizer. A study of the connections will show the method of operation. It will be seen that the main switch can be closed or opened regardless of the position of synchronizer. In general, the machine will be thrown in when there is a difference in speed of one beat in 4 to 7 seconds. The time before synchronism at which the contacts close can be regulated for the speed of operation of the various types of switches.

Ground detectors are used considerably and a word as to their operation will be valuable. They are connected to the line thru condensers only and therefore do not need to be protected for high voltage. They act by static charges, so that the needle is repelled from the grounded line. A three-phase instrument is constructed by the Westinghouse Electric

and Manufacturing Co. In case single-phase instruments are used in three-phase work, two only need be installed. Great care is required in the location of the wires, and for this reason the instrument occasionally is not put on the switchboard but on a suitable panel near the outgoing lines. The condensers for the ground detectors can be placed near the lightening arrester just before the lines leave the building.

There are three general types of instruments in use on switchboards; namely, the horizontal, edgewise Type H, made by the General Electric Co.; the vertical edgewise Type I, made by the Westinghouse Electric and Manufacturing Co.; and the general round pattern. Each type is satisfactory to such an extent that recommendation will not be made in favor of any. The room on the switchboard is a determining factor in the choice of the type. The round pattern, as perfected by the Westinghouse Electric and Manufacturing Co., is used on their instrument pedestals which are recommended later. It has large open scales which subtend an arc of 300 degrees. The pointer is long and plain and, altogether, it is very satisfactory in this connection.

The location of instruments on the switchboard or control board is a matter of considerable importance. The voltmeters are usually placed on each generator panel, and the synchronizing voltmeter is placed on top of the board or at one end on a bracket near the synchroscope. The ammeters are usually placed at the top of the panel of the respective feeder,

generator, etc. The field ammeter is then placed below this on the generator panels. On the feeder panels the ammeters are sometimes placed one under the other but this depends upon the shape of the instrument used.

As was previously stated the shape of the instrument is the determining factor in its location and this with reference to plugs, switches, etc. will be treated under switchboards.

INSTRUMENT TRANSFORMERS.

Potential.

Potential transformers are not essentially different from the ordinary transformer. The principal difference is that the exciting current is proportionally greater while the load is comparatively small for the size of the transformer. The inductance causes the current in the secondary to lag somewhat behind the current in the primary. This will cause an error in wattmeter readings, but will be considered in connection with series transformers. The excitation of this transformer causes a drop in the voltage. An example cited by J.D. Mies in a paper on "Polyphase Metering" read before the American Institute of Electrical Engineers is of a 200-watt transformer with 10000 volts primary and 100 volts secondary. The impedance would be about 1000 ohms or a drop of 200 volts with full load current. This would mean an error of 2%, but since this is a Vectorial subtraction the error is about 1.6%. This, however, for a certain number of instruments on the transformer can be compensated for in the ratio of the windings. As a rule the potential transformer can be depended upon for accuracy to within 1%. The question now arises as to the number of potential transformers to be used, and on what potentials they are to be used.

The safety of the attendant can not be overestimated while the cost of installation is also of great importance. They should be used for all voltages over 750 since standard switch-

board instruments for higher voltages are not obtainable without the use of transformers. In general one set of potential transformers is sufficient for each generator for relays, voltmeters, and wattmeters if such transformer is of proper size. The relays using potential circuits operate very seldom and the installation of a separate potential transformer is not advisable. One must be installed on the bus bars if the voltage of them is to be measured. If a wattmeter is to be used on the feeder this may or may not necessitate the use of an additional potential transformer. The cost of installing such a piece of apparatus is very expensive especially on high voltages, and the one on the bus bars will serve if no voltage regulators are used on the feeders. They should in any case be located on the low-tension side of the transformer whenever possible.

The location of the potential transformers is of considerable importance. They have to be very well insulated to avoid all possibility of a short circuit or a ground. Referring to Plate 4 we see the cell for the potential transformer, in the form of a brick compartment just in front of the generator oil switch. In the Twin City Power Co's. Station shown in Plate 5 the potential transformers are in the bus bar structure under the busses. The secondaries of the potential transformers should always be grounded to protect the attendant. For three-phase work they are usually connected open delta,

which necessitates the use of only two for a set. Fuses are always placed in the primary leads to protect against a short-circuit.

Series.

The series transformer is essentially different from the potential transformer. If the primary current be constant the secondary pressure on open circuit will be proportional to the frequency,but,if the secondary be wholly inductive,the pressure will be independent of the frequency. If the magnetizing current be kept small,the ratio of the primary and secondary current will be practically constant for all loads. In the design of a current transformer the following points must be emphasized.

1. Iron of the highest quality used.
2. Magnetic circuit short and as perfect as possible.
3. Total ohmic resistance of secondary as low as possible.
4. High self-induction.

Series transformers on the market today can be depended upon for accuracy to within 1% for nearly all loads. The angle of phase displacement between the current in the primary and secondary is of great importance when wattmeters and power factor indicators are connected to the transformer. However, as this angle is in the same direction as that in the potential transformer,the resultant angle between the two secondary currents is not far from that of the primary current and pressure

and need not introduce a serious error. The use of more than one piece of apparatus on a series transformer is not advisable for the present types. They are designed usually for five amperes on the secondary for full load on the primary and any increase or decrease in this ratio will introduce an error in the instruments. However, we find that this practice is not adhered to strictly. It is usual practice to feed an ammeter and wattmeter from the same set of transformers, while the relays employ a separate set in nearly all cases. The resistance of the common return, in case of a set of two series transformers on a three-phase system directly introduces an error in the reading equal to the I^2R loss in the return. Therefore if this is used, the resistance must be as low as possible. The effect upon series transformers by stray fields is an important one, as the primary ampere-turns are very small and the effect of a stray field is considerable. This weak field also prohibits the placing of two sets near each other. In case series transformers are used to operate relays they should always be placed on the line side of the switch they operate so that any trouble caused by the transformer itself will be cut off when the switch opens. This will hold in general for series transformers wherever there is a choice.

Series transformers need not be confined to high potentials as their use greatly simplifies the main wiring. They are advocated for currents of 200 amperes or over and should be used in connection with potential transformers for all voltages

over 750, whatever the current. For currents of [illegible] amperes or over they are made to slip over the bus bar, and in some cases are split and can be clamped on without access to an end of the bus bar, but this is not advisable as the joint is liable to increase magnetic reluctance, which is not desirable. The location of series transformers is not of as much importance as that of potential because they are only in one phase of the line, and, if the transformer itself is properly insulated, the transformer can be hung on a suitable insulator right in line with the lead to which it is attached. They are usually placed on a vertical portion of this lead. Reference to Plates 4, 5, and 6 will show this under various conditions. The secondary of these transformers should be grounded on the proper side with reference to the potential transformers. Series transformers are not of abnormal size. A few dimensions below will show the space required for their installation.

Westinghouse Type E for potentials not exceeding 24000.

Length 28"

Width [illegible] 3/4"

Depth 11"

Westinghouse Type C for potential not exceeding 2400
(Slip over Bus bar)

2000 amperes capacity

Length 8"

Width [illegible] 1/4"

Depth [illegible] 3/4".

SWITCHBOARDS.

It will be best at first to take up the location of the switchboard and then to select the type board to be used. In general, in large central stations where there are not more than three or four machines, or where there is not a great deal of attention required for the operation of the switchboard, it is very desirable to have the switchboard on the engine room floor so that an oiler or attendant about the machine can attend to the board. This would then give economy of operation. Of course, such an arrangement would not be recommended where the attendant would have several feeders to attend, since his attention would have to be divided too much.

Where the size of the central station does not warrant the installation of the switchboard on the engine room floor, it must then be located in a gallery from which the operator can observe the point of control of each of the prime movers, and thus be in close touch with the engineer for starting, stopping, and in time of trouble in the station. This arrangement will call for the addition of a man for each shift whose only duty is to attend to the switchboard.

Another feature that will determine the location of the switchboard will be the control and instrument wiring. Since this should be as short as possible it is advisable to place the switchboard near the economical center, where the cost of control leads will not be great.

In the Ontario Power Co. the operator is 800 feet from

the generators and in a seperate building. He keeps in touch with the engine rooms by means of telephone or telautograph, and he is not disturbed by the noise of the units. This of course, makes his work easier for him. He has complete control over the water-wheel governors and the motor driven rheostats for the fields. By means of a switch in the generating station the operator in the engine room can disconnect a generator, but he cannot connect a generator to the system since he has no control over the closing coil of the switch. All that the operator in the generating station has to attend to is the exciter voltage. Also, in case of trouble to an alternator he is to open the first generator switch. He keeps the operator in the distributing station informed as to the conditions in the engine room by means of the telautograph, which keeps a record of all communications. Since the board of the operator in the Generating Station is only an exciter board, it will not be taken up here.

It seems in cases of this kind, that the placing of the operator so far from the units is an advantage because he can thereby work to the best of his ability; being, as he is, in a quiet room. In this system, however, he should have an assistant to aid him in case he should have an accident. Thus an added expense is necessary for attendants, but since these installations are used in large central stations such an insurance is recommended and is, after all, only a small proportion of the total operating expenses.

There are three general types of switchboards which we have found in operation; namely, the plain marble or slate board, the pedestal and instrument post arrangement, and the bench board arrangement. The kind of material used varies in the different types; also the method of support.

There are five kinds of material used; namely, Italian marble, White Tennessee marble, Blue Vermont marble, black enameled slate, and unpolished slate. Marble or slate is used because it gives a satisfactory combination of the two essential features of a switchboard; namely, good dielectric strength, and strong mechanical support for instruments and switches.

The board is built up of slabs about two inches thick and is usually seven and one half feet high. The lower slab is about one third the total height of the board, the remaining two thirds being used for instruments and switches. These slabs are supported by means of a two inch angle iron or iron pipe framework resting on a six inch channel iron. The board is either braced from the wall or the ceiling by means of suitable angles or pipes.

The Westinghouse standard pattern is Blue Vermont marble two inches thick and mounted as mentioned above. The width of the panels varies with the number and type of instruments installed thereon. The height is controlled by the height at which it is desired to place the instruments, for there is not enough apparatus on the panel to call for a special dimension. However, it is found that when the instruments and

suitable brackets for lamps have been located, the board is about seven feet six inches high.

The number of panels in the switchboard will be controlled by the number of units, exciters, and feeders. Both systems are used.

The generator panels are equipped with the instruments and suitable lights for the reading thereof. The control for the oil switch, the indicating lamps, voltmeter receptacles, synchronizing plugs, relays, exciter switch, and field rheostat handle, are also mounted on these panels.

The feeder panels have the feeder instruments, the relays, the oil switch control, and indicating lamps. A station panel is sometimes added and it usually contains synchronizing apparatus for the duplicate bus bars, the oil switch control thereof, and the oil switch control for sectionalizing. The controls for the three tie switches shown in Plate 1. Fig. 10, are placed on a station panel.

In the case of voltages up to 2200 it has been found that the oil switches are often hand-operated, and the handle projects thru the panel and is operated from the front of the board.

To facilitate instrument wiring on the back of the plain panel boards, it is recommended that the panels be set a few inches clear of the iron framework by means of suitable clamps. The wires can then pass from panel to panel without bending around the iron work. Either iron pipe or angle iron can be

used for the iron framework.

It has been found that rheostats are often manipulated by means of a wheel placed on a pedestal in front of the switch board. The wheel is fastened to a shaft which holds a sprocket, over which a chain travels to a sprocket on the rheostat. This of course, has the advantage of keeping the mechanism out of the way of the high voltage leads or the exciter bus bar on the back of the board. It therefore simplifies the construction on the back of the board.

The use of the instrument post and control pedestal is noted in several large control stations, and it seems to be a unique arrangement in that little marble is required for its construction, there being only a small panel on the front and top of the control pedestal. Accordingly its cost is low.

The control pedestal stands in front of the instrument post, and is made of an iron frame work with a marble panel in front, which holds the control handles for the switches. In the Ontario Installation the handle for the control of the excitation and of the water wheel governor is also on this panel. The synchronizing plugs, indicating lamps and dummy bus are on this panel.

The instrument post is made of iron, and is of an ornamental design. The instrument wires are carried inside this post. It holds the instruments required. The whole arrangement can be observed by the operator as he stands before the pedestal.

This equipment is manufactured by the Westinghouse Electric and Manufacturing Co. and represents a great step toward the standardization of switchboard equipments. It is neat in appearance, the apparatus is well isolated, is not crowded, and the space occupied is not much greater than that required for the ordinary board and its clearance in the rear.

The bench board designed by the General Electric Co. is a step in the same direction. However, the isolation of separate units is not so good. The instruments are mounted on the upper part of a black polished slate panel. The top of the bench is slanted and the control handles and indicating lamps for the oil switches along with the dummy bus are located thereon. The operator has to bend over to reach some of his control handles and in doing so may come in contact with some of the apparatus on the lower part of the bench.

This latter design does not have so neat an appearance. Its straight black polished slate board with the case at the back concealing the wiring equipment, is used in the Canadian Niagara Falls Power Co., and is built in the center of a platform, beneath which the high tension cables are carried. This standing in the center of the room presents a very neat and compact arrangement. The upper part of the front of the board contains the instruments, while the middle part contains the dummy bus, the oil switch control, and the indicating lamps; and the lower part contains the relays and exciter switches.

It seems from all we have found in connection with switch-boards that nothing equals the standard of excellence set forth in the Westinghouse Pedestal and Instrument Post arrangement. It can be seen at a glance just which set belongs to a certain unit, since the sets stand out distinctly before the operator. This, therefore, adds to the simplicity of operation. Also the pedestals can be arranged in a semi-circle without additional wiring due to bending of the usual type board; and furthermore it aids the operator in locating the control for a particular machine, and brings all instruments within equal range.

In the installations at the Ontario Power Co., the recording and integrating instruments are placed on marble panels of the usual construction and located on the floor directly beneath the control pedestal and instrument post for this unit. Hence the instrument wiring does not cross from the time it leaves the cables on the first floor until it ends at the instruments.

AUXILIARY WIRING.

The auxiliary wiring in a central station consists of two classes; namely, instrument wiring and control wiring. The former class, of course, will consist of alternating current circuits, while the latter in general will include direct current circuits. The former, therefore, must have special attention in regard to induction effects, which would cause an error in the meter operation. Since the wires will necessarily be near the field of the high potential system some means should be used to shield them. Then in the case of the control leads, which, likewise, are near the field of the main circuits, the effect of induced electromotive forces must be eliminated, or the desired effect of automatic operation is disturbed.

In the wiring of potential transformers the high-tension leads are supported on suitable insulators to the primary of the transformers. The potential of the secondary side of these transformers is never over one hundred volts, and the leads are carried in a single iron conduit of suitable size to the instruments or relays. This conduit is usually laid in the concrete of the floor or carried along on suitable hangers to a point behind the switchboard panel and just above the floor. The wires are then neatly supported on the back of the switchboard and connected to the proper relays or instruments. The wiring from the series transformers is carried in similar conduit lines. The iron conduit should contain all

the phases from one set of transformers so that the self induction will be eliminated. Of course, brass pipe containing each lead could be used but the effect of external fields would not warrant its use; and further the cost of such an installation would prohibit its use.

The usual precautions in fitting up this iron conduit should be observed. The ends of the pipe should be reamed out to prevent the wire from being scraped as it is drawn in. Suitable bushings should be placed in the end of the conduit line so that there will never be a chance for the insulation of the wire to become worn off in case the wire should have to be disturbed often.

The control leads are carried from the oil switch mechanism which is usually on the top of the switch cell thru iron conduit to the center of control. The conduit in this case is carried in a manner similar to that mentioned for the instrument wiring.

In some cases, where the center of control is far from the apparatus controlled, a cable is used. This method was adopted by the Ontario Power Co. between their generating and distributing stations, a distance of 800 feet. The power house being at a lower elevation than the distributing station it was necessary to put clamps on the conduit at suitable distances to diminish the strain which would come on the top supports otherwise. These clamps are securely fastened to the sides of the rock tunnel thru which the conduit passes. At all

times these leads are kept a safe distance from the 12000 volt leads from the generators, thus preventing a chance for short circuit or other trouble. When these cables reach the control chamber they are placed in troughs, which are made of channel irons and are filled with sand. The purpose of the sand is to keep the trouble in one set of cables isolated from others and reduce the fire risk. The ends of the cables of one generator are carried to a point in the first floor below the control pedestal and instrument post for this generator. From here they rise to the terminal board on the second floor. This terminal board contains fusses mounted on the front for each wire, and the overload and reverse current relays. From this floor the wires are carried in iron conduit to the next floor where the recording and integrating instruments are located. Passing from this floor the leads go finally to the control pedestal and the instrument post which contains only the indicating instruments. On each of the panels the wiring has been done in a neat and systematic manner. As has been mentioned before, suitable plugs are mounted on the integrating and recording instrument panels so that any instrument can be calibrated. In like manner plugs are provided for the careful adjustment of relays.

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Plate 12